Ital. J. Agron., 6, 2, 133-142

Impacts of Climate Change and Elevated CO_2 on Sugar Beet Production in Northern and Central Italy

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Received: 23 January 2002. Accepted: 13 November 2002.

ABSTRACT

BACKGROUND. The yield potential of sugar beet in Italy is lower than in Central Europe. Hence, the profitability of the crop is also lower, and a future change in climate associated with global warming may put at risk the national sugar processing industry. We simulated production of sugar beet in northern and central Italy under current and future climate scenarios, the latter derived from the Hadley Centre general circulation model (GCM).

METHODS. Two future time-periods were considered for analysis, 2040s and 2090s, with atmospheric CO_2 concentrations of 450 ppm and 615 ppm, respectively. Sugar beet production was simulated in rotation with soybean, sunflower, wheat, soybean, canola and maize, at six Italian sites: Brescia, Padova, Modena, Pisa, Osimo, and Perugia in order to provide a wide range of environments in Northern-Southern Italy. The model CropSyst was used to compute above and below-ground crop growth and yield, soil water movement, and the effects of elevated CO_2 on plant photosynthesis and transpiration. Simulations under climate change included the possibility to adapt crop management to new conditions, by modifying irrigation amounts and date of sowing.

RESULTS. Simulation results indicate that sugar beet production would not be significantly affected under the climate change scenarios considered. Irrigated sugar beet yields increased at most sites under climate change, compared to present, in the range +2% to +5% in 2040 and -4% to +15% in 2090. Rainfed yields varied -4% to +10% in 2040, and -8% to +9% in 2090. At most sites increased crop-growth rates under elevated CO_2 and increased precipitation regimes were sufficient to overcome the negative effects on crop yields linked to higher temperatures. Anticipated sowing helped to maintain production under climate change at current levels. Irrigation increases of +13 to +24% were necessary to maintain irrigated sugar beet production at present levels, due to higher temperatures and increased evapotranspiration rates.

CONCLUSIONS. Results from this study indicate that sugar beet production in northern and central Italy may not be greatly affected by future climate change, if global warming will be characterized by increased temperature and increased precipitation regimes, as the Hadley Centre scenario used herein indicated. Simulations also indicated that, despite the success in maintaining or increasing yields from baseline levels using adaptation, total irrigation use may increase under future climate change, due to increased evaporative demands under global warming.

Key-words: Cropping Systems, Climate Change, Elevated CO_2, Adaptation, Sugar Beet.

INTRODUCTION

Agricultural crop production might be negatively affected under scenarios of future climate change, with potential consequences to the global food supply (Reilly et al., 2001). Many studies have indicated that elevated atmospheric CO_2 will tend to increase crop growth rates and harvest yields globally. However, the increases in temperature and changes in precipitation associated with global warming may either increase or decrease crop production in the future, depending on local conditions (Rosenzweig and Hillel, 1998). For example, warmer spring-summer air temperatures are beneficial to crop yields at northern temperate latitudes, where the length of growing seasons currently limits production. By contrast, increased temperatures tend to depress crop yields at mid-latitudes, due to shortened grain-filling periods. In Mediterranean-type environments, where high summer temperature and water stress already limit crop production, simulations with increased temperatures have shown either negative (Rosenzweig and Tubiello, 1997) or positive impacts, the latter due to successful avoidance of drought-stress (Bindi et al., 1999). Simulation studies of climate change impact on agricultural production have mostly focused on either single crop or cropping systems where most of the crops were fall-sown C3 species and spring-sown C4 species, thus lacking spring-sown C3 species such as sugar beet. In addition to climate and biophysical impacts, it is well recognized that the response of agricultural systems to future climate change will strongly depend on management practice, such as the type and levels of water and nutrient application, and on the ability of farmers to adapt to a changed climate.

The objective of this work was to study the effects of climate change and elevated CO_2 on sugar beet production in central and northern Italy. Previous work on the impacts of climate change in Italy had focused on rotation systems with wheat, maize, and sunflower in northern and southern Italy, indicating positive effects at northern sites and negative impacts in the south, largely as a function of changed water demands (Tubiello et al., 2000). That study had used scenarios of climate change that project climate under a static doubling of atmospheric CO_2 levels. New transient general circulation models are currently available, which compute climate change more realistically, through time, as atmospheric CO_2 increases. Here we use such new scenarios to analyse current and future production of sugar beet in northern and central Italy, focusing on rotations with several other crops such as maize, soybean, sunflower, canola, and wheat.

MATERIALS AND METHODS

Assessing the impacts of climate change on crop production involved the creation of climate scenarios representative of both current and climate change conditions. This required using observed and weather generated-data, as well as projections with general circulation models. Climate data were then input into a crop simulator to assess potential impacts on sugar beet production (Figure 1).

Climate data and climate change scenarios

Three climate scenarios were used for input into the crop model: 1) *Baseline*, 350 ppm CO_2, representing current climate conditions; 2) *"2040"*, 450 ppm CO_2, representing mean climate change for the period 2030-2049; and 3) *"2090"*, 660 ppm CO_2, representing conditions in 2080-2099. The two time horizon chosen herein provided respectively an intermediate and a fully-realized climate change scenario (see: Reilly et al., 2001). Each scenario consisted of a 50-year long meteorological time-series.

The baseline scenario was generated in the following manner. At each study site, we collected daily meteorological data of minimum/maximum air temperature and precipitation for available periods. Specifically: Modena (44° 40' N, 10° 55' E; years 1968-95), Brescia (45° 58' N, 10° 23' E; years 1989-98), Padova (45° 54' N, 11° 52' E; years 1984-98), Pisa (43° 19' N, 11° 21' E; years 1951-91), Osimo (43° 29' N, 13° 30' E; years 79-98), and Perugia (43 °08' N, 12° 50' E; 1989-98). Because observed solar radiation data at the simulation sites were available for shorter periods (~4 years), the model of Donatelli and Campbell (1998) was used to estimate solar radiation from temperature. Finally, we employed the weather generator ClimGen (Stockle and Nelson, 1999a) to create a 50-year baseline climate scenario from the observed data (see Table 1 for climatic data). ClimGen follows a similar approach to that introduced by

Table 1. Temperature and precipitation regimes at six study sites. Seasonal and annual mean values correspond to the baseline scenario.

Location	Oct-Jan		Feb-May		Jun-Sep		Annual	
	Air Temp. avg (°C)	Precip. cum (mm)	Air Temp. avg (°C)	Precip. cum (mm)	Air Temp. avg (°C)	Precip. cum (mm)	Air Temp. avg (°C)	Precip. cum (mm)
Brescia	6.1	284	10.1	243	21.3	266	12.5	793
Padova	5.1	470	8.7	476	19.7	433	11.2	1379
Modena	5.5	213	10.0	202	21.5	231	12.3	647
Pisa	10.2	433	11.5	274	21.4	210	14.4	918
Osimo	9.3	255	10.7	202	21.4	189	13.8	645
Perugia	8.2	279	10.6	226	21.2	230	13.3	735

Table 2. Hadley-generated climate change scenarios at six study sites. Projected increases in mean air temperature.

Air Temp. avg (°C)	Oct-Jan		Feb-May		Jun-Sep	
	2040	2090	2040	2090	2040	2090
Osimo	0.81	3.15	1.05	3.04	1.18	4.25
Perugia	0.89	3.29	1.05	3.12	1.21	4.31
Pisa	0.95	3.50	1.06	3.25	1.23	4.40
Modena	0.91	3.63	1.13	3.34	1.25	4.58
Padova	0.88	3.50	1.12	3.27	1.27	4.58
Brescia	0.85	3.53	1.14	3.35	1.28	4.43
Average	0.88	3.43	1.09	3.23	1.23	4.42

Table 3. Hadley-generated climate change scenarios at six study sites. Projected changes in mean cumulative precipitation.

Precipitation (mm)	Oct-Jan		Feb-May		Jun-Sep	
	2040	2090	2040	2090	2040	2090
Osimo	57.0	39.5	41.2	27.3	16.0	–23.8
Perugia	74.6	31.3	37.0	26.1	7.4	–35.5
Pisa	115.9	77.0	56.6	66.5	–5.4	–35.5
Modena	72.8	54.1	30.8	34.5	13.3	–24.0
Padova	69.6	23.1	15.9	10.3	4.6	–18.8
Brescia	44.0	22.7	17.3	19.1	3.2	–26.4
Average	72.3	41.3	33.1	30.6	6.5	–27.3

Richardson and Wright (1984). Precipitation occurrence (wet or dry day), determined by using a first order Markov chain, is the primarily variable conditioning the maximum and minimum temperature. The temperature generation process is based on serial and cross-correlation (maximum temperature, minimum temperature, and solar radiation) 3 × 3 matrices whose coefficients are locally calibrated.

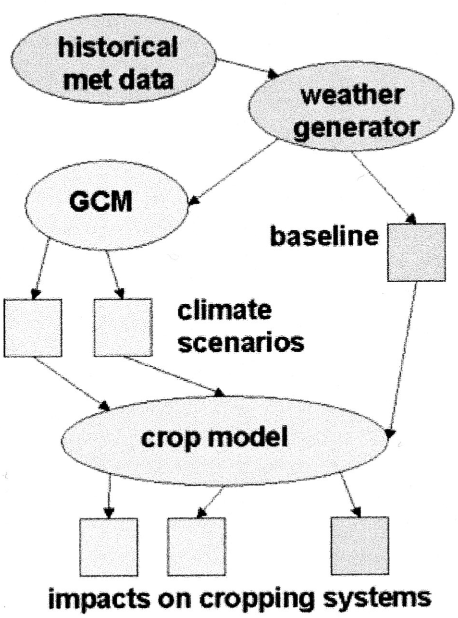

Figure 1. A schematic diagram illustrating the methodology involved in the generation of baseline and climate change scenarios, data input into a crop model, and analysis of the impacts on simulated cropping systems.

The two climate change scenarios used in this study corresponded to climate projections of the Hadley Centre atmospheric model, available to us via the US National Assessment datasets (Reilly et al., 2001). In these projections, run globally with a resolution of 2° × 2.5° long × lat, atmospheric CO_2 increased over the period 1990-2100 at a 0.5% rate, up to 700 ppm, following a "business as usual" emission scenario (IPCC, 1996). As a result, global mean temperatures rose, as much as 4 °C by the year 2100. The two climate change scenarios were generated by applying to the *baseline* dataset the changes (delta temperature increase, ratio of precipitation change. See Tables 2 and 3) specified in the Hadley GCM projections (2030-2049 or 2080-2099), downscaled to each study location and computed in monthly averages (for more details, see Tubiello et al., 2001). In this way, new, 50-year climate change series were generated from the Baseline, with mean values corresponding to the GCM-projected changes, but with the same variability as the current climate. Atmospheric CO_2 concentrations were computed for each period using the "business as usual" Is-92a emission scenario (IPCC, 1996).

Crop model

Baseline and climate change scenarios were input into a crop simulator, CropSyst (Stockle and Nelson, 1999b). This model computed water and nitrogen movement through the soil-plant continuum, crop phenological development, dry matter accumulation and crop yield. It was specifically designed for multi-year, sequential simulations of cropping systems. The performance of CropSyst has been evaluated for diverse environments (e.g., Pala et al., 1996; Stockle et al., 1997), including Northern and Central Italy under both current and climate change conditions (Donatelli et al., 1997; Tubiello et al., 2000). CropSyst, although not specifically validated for sugar beet, was successfully calibrated against sugar beet data collected in field experiments in Northern Italy (Bellocchi et al., 2002; Poggiolini et al., 2002).

As shown in Table 4, CropSyst equations calculate daily dry matter accumulation as limited by either intercepted daily solar radiation or daily crop transpiration, depending on vapour pressure deficits (VPD). Biomass computations are performed using coefficients of radiation-use efficiency, *RUE* (Monteith, 1981), and transpiration efficiency, *K* (Tanner and Sinclair, 1983; Stockle et al., 1994), that explicitly depend on elevated atmospheric CO_2 concentration (Stocle, 1992; Tubiello et al., 2000). The equations in Table 4 indicate that in CropSyst, increasing CO_2 levels enhance crop photosynthesis while decreasing canopy transpiration, and that these effects also depend on VPD. Finally, crop response to elevated CO_2 in CropSyst is different between C3 (wheat, barley, sunflower, and soybean) and C4 photosynthesis (maize and sorghum) (see Jara and Stockle, 1999). At the two atmospheric CO_2 levels of 450 ppm and 615 ppm considered in this work, RUE was respectively +12% and +25% higher than present for C3 crops, and +5% and +10% higher for C4 crops. The corresponding simulated reduction in transpiration efficiency was similar between C3 and C4 crops, and was -17% at 450 ppm and -38% at 615 ppm.

Cropping systems simulations

Sugar beet production was simulated in different rotations with soybean, sunflower, wheat, soybean, canola and maize, depending on the typical cropping system of each location (Table 5). Such a cropping system approach is necessary to realistically simulate through time the movement of nutrients through the soil and the patterns of water use, upon which crop productivity and farm viability depend. Also, we favoured simulating rotations in order to minimize the effect of soil sickness that would occur in real systems, and which is not accounted for by CropSyst.

We assumed optimal nitrogen fertilisation for

Table 4. Equations for calculation of biomass production at given CO_2 concentrations in CropSyst.

Biomass Production	$B = Min\ (\varepsilon\ IPAR, K\ T)$
Effective Transpiration efficiency	$K=k/VPD$
CO_2 dependence of ε	$\varepsilon = Gratio*\varepsilon_0$
CO_2 dependence of k	$k = Gratio*k_0 /F$
CO_2 dependence of r	$r = r_0*([CO_2]/350) / Gratio$
CO_2 dependence of F	$F= (\delta+\gamma\ (r_0+r_a)/r_a) / (\delta +\gamma\ (r+ r_a)/ r_a)$

K = Canopy water-use efficiency
IPAR = Intercepted Photosynthetically-Active Radiation
ε_0 = Crop radiation-use efficiency at reference CO_2 concentration (350 ppm)
ε = Crop radiation-use efficiency at specified CO_2 concentration, $[CO_2]$
k_0 = Crop water-use efficiency at reference CO_2 concentration
k = Crop water-use efficiency at specified CO_2 concentration
T = Crop transpiration at specified CO_2 concentration
VPD = Air vapour pressure deficit
Gratio = Ratio of potential growth at specified to reference CO_2 concentration
F = Ratio of transpiration at specified to reference CO_2 concentration
r_0 = Canopy resistance to water-vapour transfer at reference CO_2 concentration
r = Canopy resistance to water-vapour transfer at specified CO_2 concentration
r_a = Aerodynamic resistance to water-vapour transfer
δ = Slope of the saturation vapor pressure function of temperature
γ = Psychrometric constant

Table 5. Cropping systems simulated at six study sites.

Brescia and Padova
- maize-soybean-maize-sugarbeet
- maize

Modena
- sugar beet-wheat-soybean-wheat
- maze

Pisa
- sugar beet-wheat-soybean-wheat
- sunflower-wheat-canola-wheat
- maize

Osimo and Perugia
- sugar beet-wheat-soybean-wheat
- sunflower-wheat-canola-wheat

all crops. Two sets of simulations were run at all sites for all crops: irrigated and rainfed. Irrigation water was simulated as applied automatically, based on maximum soil moisture depletion of 50% plant available water in the upper 0.7 m of the soil profile.

Finally, adaptation techniques were simulated at each site under the climate change scenarios, to investigate the effects of simple management solutions largely available to the farmer even today. The adaptation strategies simulated were earlier planting of spring crops and modified irrigation regimes. Early planting of spring crops helps to avoid plant drought and heat stress during the hotter and drier summer months predicted under climate change. Increase in irrigation water amounts, where additional resources are available, and/or changes in seasonal distribution, alleviate crop water stress under the warmer growing conditions typical under climate change scenarios.

Planting of spring-sown crops was anticipated by 15 and 30 days with respect to the baseline case. Irrigation amounts were increased as needed and automatically computed with CropSyst, within the irrigation scheme previously described.

RESULTS AND DISCUSSION

Baseline simulations

The locations selected, although not geographically distant from each other, were characterized by remarkably diversified temperature/precipitation patterns (Table 1). In particular, mean temperature increased along a north-south gradient, but precipitation patterns were less homogeneous. The driest sites were Modena and Osimo, with a cumulative precipitation of 650 mm. The wettest site was Padova, with 1379 mm, followed by Pisa.

Under rainfed conditions, we investigated sensitivity of sugar beet yields to low and high soil water-holding capacity (LWHC and HWHC), as soil depth is a key factor affecting plant water availability (and harvest yield) under low precipitation. As shown in Table 6, for the LWHC soils simulated harvest yields ranged 5.6-9.5 t ha^{-1}; HWHC soils had higher sugar beet yields, in, the range 7.0-10.8 t ha^{-1}. Simulated values and their regional distribution well reproduced observed data (Agronomica-Eridania, pers. comm.). In Italy, sugar beet yields diminish following a north-south gradient, due to increasing evapotranspiration demands and crop stress. In addition, most rainfed sugar beet crops are produced on soils with high water holding capacity, especially under conditions of low precipitation.

Table 6. Sugar beet yield (roots dry weight) and coefficient of variability (CV) at six study sites, for the three climatic scenarios, and for high and low water holding capacity soils.

Location	Soil	base line		2040		2090	
		t ha^{-1}	CV	t ha^{-1}	CV	t ha^{-1}	CV
Brescia	HWHC	10.8	15.5	10.3	15.5	9.9	12.5
	LWHC	9.5	15.5	10.3	15.5	9.9	12.5
Padova	HWHC	10.6	12.3	7.8	20.9	9.9	13.0
	LWHC	7.0	21.3	7.8	19.0	7.6	22.1
Modena	HWHC	9.6	10.4	10.6	13.4	10.4	15.0
	LWHC	8.1	20.7	9.1	21.3	8.5	21.4
Pisa	HWHC	8.3	16.0	9.2	16.2	8.9	16.4
	LWHC	5.9	20.5	6.5	20.7	6.1	23.5
Osimo	HWHC	7.2	18.5	8.1	19.3	7.2	16.1
	LWHC	5.3	23.5	6.1	25.0	5.1	21.0
Perugia	HWHC	7.0	18.1	7.8	15.2	7.5	13.6
	LWHC	5.6	21.0	6.1	23.0	5.9	22.5

Accordingly, the larger sugar beet yield gains between low and high water-holding capacity were simulated at the sites with lower precipitation to evapotranspiration rates, such as Perugia and Osimo (more than 50% gain). At the other sites, characterized by high precipitation to evapotranspiration rates, soil water holding capacity became less important in determining yield.

Finally, we computed the coefficients of variation of yield (CV), defined as the ratio of mean yield over its standard deviation. Under rainfed conditions, CV coefficients give a measure of farm production risk. Simulated CVs were in the range 15%-24%.

Simulated irrigated production of sugar beet was fairly homogenous across the study sites, in agreement with reported data (Agronomica-Eridania, pers. comm.). Unlike rainfed simulations, simulated irrigated yields, in the range of 10-12 t ha^{-1}, were 10-15% higher than reported farm data for sugar beet, and more representative of production at experimental sites. This is because the leaf spot pathogen, *Cercospora beticola*, and *Rizomania*, present in Italian fields, but not simulated in CropSyst, are important limiting factors to sugar beet production. By contrast, under rainfed conditions, water stress, which is simulated by the model, is also a limiting factor to production.

Climate change without adaptation

Sugar beet production was simulated at each location under climate change scenarios. The climate scenarios produced by the GCM (see Tables 2 and 3) showed a consistent increase in mean temperature at all sites, averaging annually about 1 °C in 2040 and 3.7 °C in 2090. The projected warming was more intense during the spring-summer months, averaging across sites as little as 0.9 °C in 2040 (Oct-Jan), and as much as 4.4 °C in 2090 (Jun-Sep). Rainfall projections were rather consistent across sites, indicating an increase during the autumn-winter months compared to the summers. Precipitation increases were more pronounced in 2040, averaging +100 mm across sites in the period Oct-May, but only +6.5 mm in the Jun-Sep. In 2090, milder precipitation increases characterized the Oct-May period (+70mm), but a significant decrease was projected for the summer months (-27.3 mm).

Under rainfed conditions, with the exception of Brescia and Padova HWHC soils, rainfed sugar beet yields increased +1% to +10% in 2040, and slightly less, +1% to +8%, in 2090 (Table 6). These simulated increases were due to a combination of positive CO_2 effects on crop growth, and increased precipitation in the period Oct-May, overcoming negative effects on crop yield of higher temperatures. Although precipitation increases were smaller in 2090, CO_2 concentration was critically higher than in 2040, overcoming negative climatic effects. Yield decreases were simulated under HWHC soils at Brescia and Padova. At these two sites, with high baseline precipitation regimes, high water holding capacities buffered the positive effects of increased precipitation on future crop yields. Therefore the impacts of higher temperature and increased evaporative demands during the summer months became critical compared to the other study sites. At Brescia and Padova sugar beet yields in HWHC soils decreased under both climate change scenarios, in the range -8% to -4%, and as much as -25% at Padova in 2040.

Irrigated sugar beet yields were simulated to increase under climate change at most sites, in the range +2% to +5% in 2040, and -5% to +15% in 2090 (Table 7). There was little interaction between irrigation and climate scenarios, in the sense that roughly the same impacts of climate change on sugar beet yields were computed for both rainfed and irrigated conditions (Figure 2).

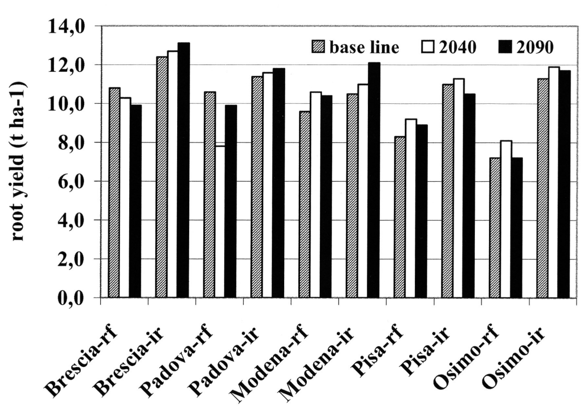

Figure 2. Graph summarizing results for simulated sugar beet production at six Italian locations, showing the effects of irrigation management on harvest yield under baseline and climate change scenarios.

Climate change with adaptation
Small negative effects simulated under climate change on sugar beet production were overcome by early sowing. Anticipation of 15 and 30 days with respect to current practices reduced water stress by providing drought avoidance in both 2040 and 2090. At the same time, a lessening of drought stress as a limiting factor to crop growth lead to improved crop response to CO_2 levels (compared to the non-adapted case), so that under such adaptation future simulated yields were consistently higher (~10%) than baseline production (Figure 3). However, no risk analysis was performed with regards to risk of frost, which limits the ability to anticipate planting under current climate. In fact, our simulation results of such adaptation techniques may be overestimated., as frost damage was not implemented into the model used in this work. Adaptation of irrigation was automatic, so that additional water was supplied to the crop as needed, as a function of changed water stress under climate change. Given the projected increases in precipitation forecast by the GCM used in this work, modest increases of applied water were required to optimize future simulated production, in the range +13 to +24% across sites and scenarios (data not shown). Finally, by analyzing simulated impacts on rainfed and irrigated conditions, our simulations indicate that at Padova a shift from rainfed to irrigated management might be necessary, provided additional water is available, to restore climate change production levels to their baseline values.

Limitations and uncertainties of modeling study
A number of limitations apply to this simulation study. From a climate change perspective, it should be noted that the scenarios analysed herein are only one possible representation of future climate change over Italy. Although projections of future temperature change are fairly homogeneous across current GCMs, predictions of precipitation change, especially their regional patterns, are much more uncertain. The Hadley scenario used in this study predicts rather "wet" climates under global warming, but other GCMs scenarios have predicted drier future climates. In addition, we considered only changes in mean climate variables, while maintaining interannual variability at present values.

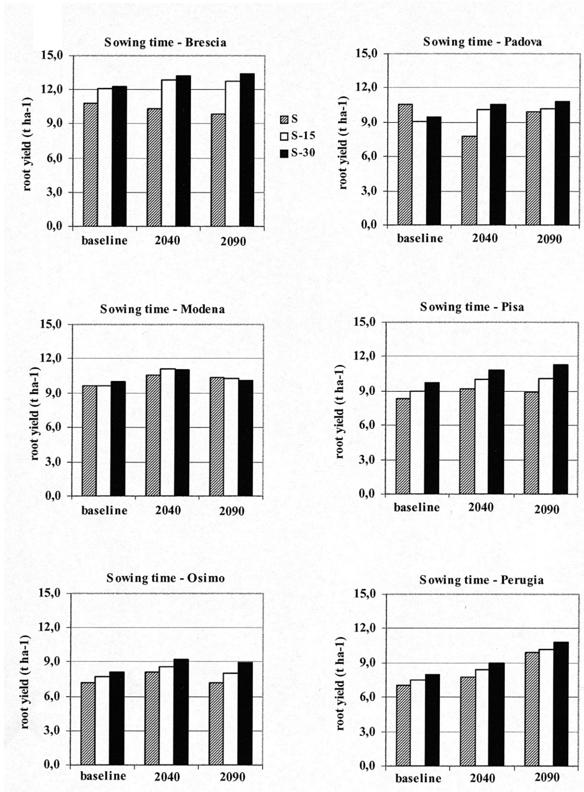

Figure 3. Graph summarizing results for simulated sugar beet production at six Italian locations, showing the effects of adaptation of early sowing (15 and 30 days with respect to current practice) on harvest yield under baseline and climate change scenarios.

Larger variability of temperature and precipitation in climate scenarios might result in additional negative effects of climate change on simulated crop yields (e.g., Mearns et al., 1992). Finally, an inherent limitation to this and all current climate impact assessments for agriculture is represented by a lack of consistent dynamic linkages between regional climate change projections and the specific conditions at the sites where the crop models are used. In short, projecting future climates at specific sites should in-

Table 7. Sugar beet yield (roots dry weight, t ha^{-1}) under irrigated conditions.

Location	base line	2040	2090
Brescia	12.4	12.7	13.1
Padova	11.4	11.6	11.8
Modena	10.5	11.0	12.1
Pisa	11.0	11.3	10.5
Osimo	11.3	11.9	11.7

clude a number of soil-plant-atmosphere feedbacks. These considerations, however, are mostly relevant as computational scale and coupling issues, with larger implications for climate modeling and climate prediction than for crop assessment science. To this end, crop assessment studies consider the climate scenarios as given and physically consistent sets, thus simply estimating one-way interactions of climate on plant production.

From a crop physiology perspective, the reader should note that the simulated effects of elevated CO_2 on crop yield and transpiration, derived from controlled-environment studies, may be limited in the field by a variety of co-limiting factors (nutrients, soil quality, pest and weed interactions, diseases, etc.) so that our simulation results should be regarded as providing upper limits to the actual field response to elevated CO_2 (e.g., Tubiello et al., 1999). Most importantly, the model CropSyst did not include a specific temperature dependence affecting root formation in sugar beet. Although the simulated levels of baseline production were in agreement with reported data, projected yields under climate change may be overestimated in this work, due to additional potential negative effects of higher temperatures on roots development.

Finally, no estimate of the effect of diseases such as leaf spot was made.

CONCLUSIONS

Results from this study indicate that sugar beet production in northern and central Italy may not be greatly affected by future climate change, if global warming will be characterized by increased temperature and increased precipitation regimes, as the Hadley Centre scenario used herein indicated. In this and other "wet" scenarios of climate change, increased precipitation regimes and elevated CO_2 were enough to counterbalance the negative effects on crop yields linked to higher temperatures and increased water stress. It is possible however that increased wetness under global warming might reduce crop yields, through effects that are not yet included in our crop models (soil saturation, flooding, etc.), as recent work indicates (Tubiello et al., 2001, Rosenzweig et al., 2002). Also, increased wetness might favour the development of cryptogamic diseases, increasing the use of pesticides.

In agriculture, the impact of management will continue to be fundamental in determining crop systems response to change. Our simulations indicated that simple adaptation strategies, involving early planting and increased irrigation application, could successfully overcome small negative effects of climate change, maintaining or even increasing production compared to present.

Finally, our simulations indicated that, despite the success in maintaining or increasing yields from baseline levels using adaptation, total irrigation use may increase under future climate change, due to increased evaporative demands under global warming.

ACKNOWLEDGEMENTS

We wish to acknowledge the Italian Ministry of the Environment for funding that made part of this study possible.

Marcello Donatelli was also funded by the *Progetto Bietola* of the Italian Ministry of Agriculture and Forestry. Francesco Tubiello was partially supported by NSF International Grant 0107320.

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IMPATTO DEI CAMBIAMENTI CLIMATICI E DELL'INCREMENTO DELLA CONCENTRAZIONE ATMOSFERICA DI CO_2 SULLA PRODUZIONE DELLA BARBABIETOLA DA ZUCCHERO NELL'ITALIA SETTENTRIONALE E CENTRALE

SCOPO. Il rendimento potenziale di barbabietola in Italia è minore che in Europa Centrale. Di conseguenza, i margini di profitto sono meno elevati, così che i potenziali cambiamenti climatici previsti per l'Italia potrebbero mettere a rischio l'industria saccarifera nazionale. In questo lavoro abbiamo simulato la produzione di barbabietola nell'Italia Settentrionale e Centrale utilizzando scenari climatici sia attuali che futuri, questi ultimi generati utilizzando il modello di circolazione generale dell'Hadley Centre.
METODO. La nostra analisi utilizza due periodi futuri: la decade del 2040 e quella del 2090, con concentrazioni atmosferiche di CO_2 pari a 450 ppm e 615 ppm, rispettivamente. La produzione di barbabietola è stata quindi simulata, in rotazione, con soia, girasole, colza e mais, in sei siti Italiani: Brescia, Padova, Modena, Pisa, Osimo e Perugia, così da rappresentare un ampio spettro di ambienti nel centro- nord. Si è utilizzato il modello CropSyst per calcolare crescita di biomassa epigeica ed ipogeica, produzione radici, bilancio idrico nei suoli, nonché gli effetti di concentrazioni atmosferiche elevate di CO_2 su fotosintesi e traspirazione. Le simulazioni da noi svolte in condizioni di cambiamenti climatici includevano la possibilità di adattare l'attuale pratica agronomica alle nuove condizioni climatiche, attraverso la modifica delle applicazioni irrigue e delle date di semina.
RISULTATI. I risultati delle simulazioni indicano che la produzione di barbabietola non dovrebbe essere significativamente alterata dagli scenari climatici qui considerati. In irriguo, i dati delle simulazioni con cambiamento climatico indicano un aumento del rendimento della barbabietola nella maggior parte dei siti considerati, da +2% a +5% nel 2040 e da -4% a +15% nel 2090. In asciutto, i cambiamenti simulati di rendimento di barbabietola sono risultati da -4% a +10% nel 2040, e da -8% a +9% nel 2090. Nella maggior parte dei siti considerati, la più elevata concentrazione di CO_2 e le maggiori precipitazioni sono stati fattori sufficienti a controbilanciare gli effetti dovuti alle temperature elevate degli scenari climatici. L'anticipazione delle semine ha contribuito a mantenere il rendimento di barbabietola a livelli simili a quelli attuali. Incrementi irrigui da +13% a +24% sono stati necessari per mantenere la produzione in irriguo ai livelli attuali, a causa delle elevate temperature e della maggior domanda di evapotraspirazione.
CONCLUSIONI. I risultati della presente ricerca indicano che la produzione di barbabietola da zucchero in Italia settentrionale e centrale può non essere molto influenzata da future modificazioni del clima, quando esse siano caratterizzate da un incremento combinato della temperatura e delle precipitazioni, così come suggerito dal modello dell'Hadley Centre. Le simulazioni indicano inoltre che l'uso di acqua irrigua potrebbe aumentare in conseguenza dei futuri cambiamenti climatici a causa della maggiore domanda traspirativa della coltura.

Parole chiave: sistemi colturali, cambiamenti climatici, CO_2 atmosferica, adattamento, barbabietola da zucchero.